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Crowd-Sourced Digitisation of Cultural Heritage Assets

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Abstract—With the rise of digital content and web-based technologies, archaeologists and heritage organisations are increasingly striving to produce digital records of archaeology and heritage sites. The large numbers and geographical spread of these sites means that it would be too time-consuming for any one team to survey them. To meet this challenge, the HeritageTogether project has developed a web platform through which members of the public can upload their own photographs of heritage assets to be processed into 3D models using an automated photogrammetry work flow. The web platform is part of a larger project which aims to capture, create and archive digital heritage assets in conjunction with local communities in Wales, UK, with a focus on megalithic monuments. HeritageTogether is a digital community and community-built archive of heritage data, developed to inspire local communities to learn more about their heritage and to help to preserve it.

Index Terms—photogrammetry; co-production; archaeology

I. INTRODUCTION

There are many challenges facing archaeologists and heritage organizations attempting to preserve sites with cultural heritage value. Many of these sites are under threat of erosion and damage from the natural forces of the weather and changes in the landscape, both naturally and through urban development. A digital record can be used to document sites in their current state, allowing future, off-site analysis and comparison between different sites.

Photogrammetry is a technique used for creating digital records of site; it allows the construction of a 3D model of an object from a series of photographs taken from known positions around that object. Structure-from-Motion (SfM) is an elaboration on the original technique of photogrammetry: a work flow which allows the use of photographs with no prior knowledge of the position

at which they were taken (McGlone et al. 2004, Behan 2010).

In modern archaeology, photogrammetry has become an established technique for recording data for various reasons, such as documenting sites (Yilmaz et al. 2007, Kjellman 2012), excavations (Grussenmeyer et al. 2004, De Reu et al. 2014), the exterior structure of buildings (Bitelli et al. 2006, Ducke et al. 2011, Green et al. 2014), monitoring erosion (Fujii et al. 2009), and recording artefacts (Mudge et al. 2010). The technique has become popular as it allows the recording of data in a non-destructive manner, and can be accomplished with an off-the-shelf digital camera. Commercial photogrammetry software packages are expensive, often beyond the budget of many archaeology projects. Open source solutions exist, but are perceived as requiring a great deal of proficiency with software to use (Green et al. 2014). Despite the expense, commercial packages are often favoured for offering graphical user interfaces which are perceived as more ‘user-friendly, which is stifling progress for the adoption of open source solutions in archaeology.

The HeritageTogether project is focused on performing photogrammetric surveys to create digital records of megalithic monuments such as standing stones, stone circles, cairns and burial chambers in Wales, UK (Karl et al. 2014); an example is shown in figures 1 and 2. While a dedicated survey team could travel to each of these sites to perform a high quality survey, due to the large number of sites it would take many days and thousands of hours to accomplish these surveys. For instance, there are about 330 cairns alone, in the north-west of Wales; a large proportion of these sites are of national importance, and are protected by the Welsh Government as Scheduled Ancient Monuments.

To break down the work flow and help us to document



Fig. 1: Photograph of Bodowyr Burial Chamber on Anglesey, UK; a Neolithic chambered tomb and Scheduled Ancient Monument in the care of Cadw, the Welsh Government's historic environment service.



Fig. 2: 3D model of Bodowyr Burial Chamber on Anglesey, UK, created using a set of 257 photographs, including figure 1.

more sites, we have adopted a crowd-sourcing approach – with the involvement of the general public, it will be possible to visit and document many more sites.

Our system incorporates SfM into a broader, community-based work flow: we perform a metric survey through the use of photogrammetry where contributors take photographs of the site, allowing us to create a 3D model of the environment. In recent years, digital cameras have increased in resolution, lowered in cost and become a common household technology; since photogrammetry does not require photographs to be taken using specialist equipment, it is a suitable task for the general public to perform. A suitable camera

resolution (>6 megapixels) can even be found in some modern smart phones.

Alongside the development of our system, we are engaging the public throughout the year with workshops, exhibitions and demonstration events at sites to support our community-based approach. Through the project we aim to co-produce the largest national photographic archive of megalithic monuments, inspire the local communities to learn more about their heritage and provide alternative views of the monuments by producing the 3D models.

This paper presents our system “HeritageTogether.org”, which creates 3D models from photographs taken by the public. We present the separate components that we have implemented, including:

- 1) how we utilize the web to collect the photographs from the users and manage the 3D models (the *website work flow*).
- 2) how we developed the website using open source software, and are following an open access approach throughout the project,
- 3) the individual components of our automatic photogrammetry work flow; which uses SfM and 3D model mesh creation functions that creates an X3D file suitable for display on the website (the *SfM work flow*), and
- 4) the *output work flow* that displays the data to the user.

II. BACKGROUND & RELATED WORK

There are three main aspects to the project that will be covered in the following sections: Structure-from-Motion, virtual heritage and community and crowd-sourcing in the field of archaeology.

A. Structure-from-Motion

Structure-from-Motion (SfM) was developed in the 1990s; a technique which allows the interpretation of 3D structure from a series of sequential 2D images which contain some motion information (Koenderink & van Doorn 1991). SfM approaches have been recently popularised through a range of web based cloud-processing engines; these tools make use of user-uploaded, crowd-sourced photography to generate the necessary photographic coverage of a site of interest and automatically generate sparse point clouds from the photographs (Westoby et al. 2012).

The principles of SfM are based on the automatic identification and matching of features across multiple images. These features are tracked and matched between

each image, enabling camera positions and coordinates to be estimated, then refined with each iteration and additional image analysed. Unlike traditional methods of photogrammetry, SfM lacks the scale and uniform orientation provided by surveyed control points. As such, each point cloud is generated in a world coordinate system, and must be aligned before it is used. To utilise a real world coordinate system, physical targets can be deployed, enabling each target location to be surveyed and recorded (Westoby et al. 2012).

Ease of use, speed of recoding and improvements in processing capability over traditional methods have made this a popular technique for producing 3D digital content for virtual heritage projects.

B. Virtual Heritage

The HeritageTogether website is a combination of a community photographic collection, a web-based photogrammetry service and a virtual museum of the monuments recorded by the contributors. The concepts of web-based photogrammetry and virtual museums are by no means new ideas, but have not yet been combined for the purpose of creating a community-built archive and museum.

1) *Web-Based Photogrammetric Services:* Web-based photogrammetric services such as Autodesk's 123D Catch (Autodesk n.d.), Microsoft's Photosynth (Microsoft n.d.), ARC 3D (Vergauwen & Van Gool 2006, Tingdahl & Van Gool 2011) and the CMP SfM Web Service (Center for Machine Perception, FEE, CTU Prague n.d.) accept uploads directly from the user and return a 3D model; however, there is little sense of community. 123D Catch and Photosynth host galleries featuring users' models; ARC 3D and CMP SfM Web Service are services for processing and have no online community aspects. The Architectural Photogrammetry Network Tool for Education and Research (ARPEN-TEUR) (Grussenmeyer et al. 2002) provided a different kind of online photogrammetry tool, though it is no longer accessible. The system provided was a photogrammetry software package developed in Java and running through a web applet, which allowed the user to access the full features of the software as though it were a local program but the data would be sent to a server for processing.

The Photo Tourism project (Snavely et al. 2006, Snavely, Garg, Seitz & Szeliski 2008, Snavely, Seitz & Szeliski 2008) and Google Map's Photo Tours used photographs uploaded by multiple users to external photography sites – Flickr for Photo Tourism, and Picasa and

Panoramio for Photo Tours. Photo Tourism developed into the Building Rome in a Day project (Agarwal et al. 2011), in which 150,000 photos uploaded to Flickr with the tag 'Rome' or 'Roma' were processed using the Bundler SfM software package in under 24 hours. The intention was to capture the entire city, but the photographs were clustered around popular tourist attractions, such as the Colosseum and the Pantheon.

None of the web-based photogrammetric services mentioned directly offer a community aspect, further than displaying examples of the models created by other users. Photo Tourism and Photo Tours scrape photographs from external photography sites which features social and community aspects, but do not host a digital community.

2) *Virtual Museums:* The term 'virtual museum' can be applied to many different aspects of engaging with a museum through the use of technology. While technology-based exhibits have existed in-situ inside museums for many years, a form of virtual museum that is rising in popularity is the virtual online collection. Virtual Museums and virtual online collections are fast becoming popular amongst physical museums as a method of displaying their collections to a wider audience (Carrozzino et al. 2013); examples include the Virtual Vermont Archaeology Museum (Peebles 2009), the Virtual Hampson Museum Project (Payne & Cole 2009), the Herbert Virtual Museum (Petridis et al. 2013) and the 3D Petrie Museum of Egyptian Archaeology (University College London n.d.a).

An example of a virtual museum existing inside a physical museum can be seen in two interactive applications developed for the Herbert Museum: a phone application to guide visitors around the museum and provide additional information, while a serious game that allows the exploration of the priory undercroft of a Benedictine monastery in Coventry, UK. The game allows the user to interact with virtual characters and learn more about the life and daily activities of the monks. The virtual Vermont Archaeology Museum, the Virtual Hampson Museum Project, the 3D Petrie Museum and the Smithsonian X 3D provide examples of virtual online museums, where portions of the museum's collections have been digitised and made accessible online to view.

The Smithsonian Institute claims that a mere 1% of their collections are on display in the museum galleries, and propose that their virtual museum project, the Smithsonian X 3D, will be "the end of "do not touch"" and provide an opportunity to present the remaining unseen 99% of their collections (Smithsonian Institution

n.d.). The Smithsonian X 3D virtual online collection is powered by the Beta Smithsonian X 3D Explorer, developed by Autodesk. The software allows the virtual visitor to manipulate the model, change the position and colour of the light sources and open a split screen to view multiple models. It also features a virtual tape measure which allows measurement of the physical size of the real model and the creation of cross-sections. Virtual visitors are invited to take a tour of the model, where an information sidebar displays information about the scanned object or place; as the tour progresses, the model is automatically manipulated to accompany the information with relevant views. All of the models have been prepared for 3D printing and can be downloaded directly in Stereolithography (STL) format. The Smithsonian X 3D is also making associated data sets available to download; for example, for the model of a fossilised dolphin skull, a full-resolution model created from Computerised Tomography (CT) scan data and the original CT scan data can be downloaded.

Recent improvements in 3D graphics on the web have resulted in a rise in popularity of the presentation of online collections of heritage assets in virtual museums. The collections in these virtual museums are generally assets in the care of the presenting museum, and the models are built by museum curators and archaeologists; they do not involve the community or crowd-sourcing. HeritageTogether presents a collection of models from outdoor locations across Wales, created in collaboration with members of the public.

C. Community and Crowd-Sourced Archaeology

Archaeology has had a long history with both communities and crowd-sourced involvement in projects, though it has largely been through local excavations and community based field surveys. More recently, the popularity of online community archaeology has grown, with many new projects for collecting data from communities or using online volunteers. The popularity of such projects recently prompted the Arts and Humanities Research Council to fund eleven new projects under the call of "Digital Transformations in Community Research Co-Production".

History and a sense of heritage in Wales is often contained within the local communities in which it is born; in an attempt to collect and document some of these personal stories, the People's Collection Wales was created (*People's Collection Wales* n.d.). Through the project, people are invited to tell the stories of their heritage by uploading their own photographs, sound

recordings, documents, videos and written stories to the People's Collection Wales website.

Cymru1900Wales (*Cymru1900Wales* n.d.) is a project dedicated to digitising an Ordnance Survey map of Wales from 1900. Contributors work on an online map interface by finding any text on the map, creating a marker pin and typing the text they can see.

Focusing on crowd-sourcing work and crowd-funding for projects as opposed to gathering information from volunteers, MicroPasts (University College London n.d.b) is a platform created specifically for volunteers and projects in heritage, history and archaeology applications. Volunteers can sign up to the platform to get involved with the projects on offer, while projects can join the platform to find volunteers from a relevant audience.

The Hillforts Atlas project (School of Archaeology, Oxford University n.d.) by the School of Archaeology, Oxford University employs a more traditional method of collecting information by simply asking volunteers to complete a written survey form about the hillforts they visit, and return them via the Hillforts Atlas project website.

III. HERITAGETOGETHER.ORG

The website front end consists of three main areas:

- 1) the main body of the website – an 'information hub' through which material about the project can be disseminated;
- 2) a gallery area to manage image uploads and display the models produced; and
- 3) a forum to allow interaction between users and project team members.

As the project is being led from Wales, UK – with a primary focus on the north-western counties of Gwynedd and Anglesey – the majority of the content for the website has been produced bilingually in English and Welsh. The website is, by default, displayed in the primary language of the user's browser, but can also be specified during the registration phase.

Users who wish to contribute to the project by uploading their photographs, or by participating in forum discussions and following the progress of the project must register as a member of the website. As the information hub, gallery and forum are managed by separate software packages, a bridge is used to ensure users are logged in to all sections of the website. To ensure ease of access to the users, it is possible to sign in to the website using their Facebook credentials.

A. Information Hub

The information hub of the site is run using the WordPress content management system to ensure ease of use to all project team members. The primary function of the information hub is to announce news of the project, publish guides on how to contribute to the project and advertise workshops and events organised by the community outreach team.

An interactive map guides users to the locations of 2,550 sites of interest. Location data for the sites has been provided by the Royal Commission on the Ancient and Historical Monuments of Wales' (RCAHMW) site archive, the National Monuments Record of Wales (NMR), which also contains data from the four Welsh Archaeological Trusts. Accessibility to the listed sites—both in terms of practicality and permission from the land-owner—is largely unknown, and our contributors are encouraged to be cautious and respectful.

A smaller number of select sites, designated 'Star Sites', are to be recorded in greater detail by the project team members as demonstrations during community events. Artefacts from the sites which are displayed in local museums are being digitised using a NextEngine desktop 3D laser scanner, and will be available to view on the website as an addition to the site model.

B. Gallery

Images taken by contributors and project team members alike, are uploaded to the gallery section of the website. The gallery is driven by Coppermine Photo Gallery (Coppermine Development Team n.d.), an open source PHP web gallery software package which is managed by a MySQL backend.

The gallery is divided into three sections: the images taken by the project's survey team; images taken by community contributors; and the 3D models produced from the images. The images and models uploaded to the gallery can be rated and commented on by members, further enhancing the sense of community in the gallery.

There are several methods for displaying 3D graphics through a web browser (for a review, see (Evans et al. 2014)); X3DOM (Behr et al. 2009) has been used on the HeritageTogether gallery to avoid requiring the user to download any plug-ins. X3DOM is an open-source framework which uses WebGL to integrate X3D and HTML5. Unfortunately, WebGL is not supported on Safari without enabling developer tools, and is prohibited completely on iOS devices. For this reason, a second gallery is currently maintained with static images of the models, to allow all to view them, but we hope to be able

to provide a true alternative for iOS and Safari users in time, without requiring the modification of a user's personal browser settings. To enable viewing through the browser, the models have been greatly reduced in resolution, but employ high-quality textures to mask the low resolution model; the models can be manipulated through basic zoom and rotation features using a mouse.

C. Forum

The forum section of the website allows users and contributors to interact with each other and the team. Users are invited to share their experiences of visiting sites, offer suggestions for the project and website, initiate discussions and ask questions of the archaeologists working on the project. The forum is powered by the Simple Machines Forum (Simple Machines n.d.) open source forum software package.

IV. THE HERITAGETOGETHER PLATFORM WORK FLOW

The automated photogrammetry work flow fits into a larger work flow structure encompassing the entire HeritageTogether platform; the complete structure is illustrated in figure 3.

A. Fieldwork

The first stage of the work flow direct involves the community members of the project. The map section of the website supplies the locations of all of the prehistoric sites we are currently trying to survey with the help of the community. Contributors can establish the location of a site either directly via the map data or using the directions link held within the site information. Once a site has been chosen the contributor must ensure they have permission to access the site in question, and that it is easily accessible. The contributor can then visit the site and take photographs; guidance on how best to take photographs is provided on the project website.

B. Website Work Flow

When the location has been established and the site photographed, contributors are able to upload the images directly to the project's server and thus begin the photogrammetry process. Once the image upload is complete, additional site information can be appended to the images, such as site location, condition, national grid reference and the sites unique identification number NPRN (National Public Records Number). This community collected information provides the images with added archaeological value, providing information about the current welfare and status of the heritage assets.

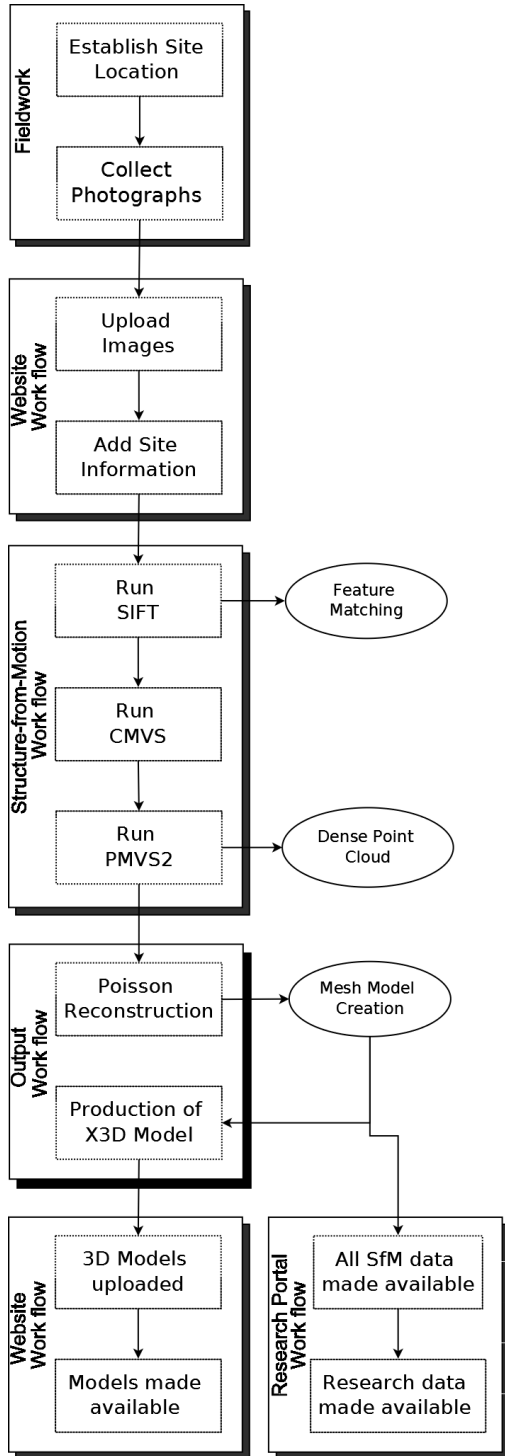


Fig. 3: Work flow for the HeritageTogether platform.

C. Structure-from-Motion Work Flow

After the images have been loaded onto the gallery system and the database entries updated for the site, the automated photogrammetry system is initialised. The system is activated by selecting the album containing

the images for the site of interest and clicking the photogrammetry button. This button activates a batch script process which collects the file locations of all the images, outputs a text file and then starts the full SfM processes, beginning with keypoint extraction. At present the automated photogrammetry system can only be activated by a member of the administration team, however, we plan on expanding this to community contributors who have dedicated time to the project in the near future.

1) *Image Acquisition and Keypoint Extraction:* SfM determines 3D locations by matching features across multiple photographs, taken from different angles. The initial step in the process is to identify features in individual images which may be present in corresponding images. One solution for this feature matching is the Scale Invariant Feature Transform (SIFT) object recognition method popularised by Snavely (Snavely, Garg, Seitz & Szeliski 2008, Snavely, Seitz & Szeliski 2008). The HeritageTogether implementation of SfM uses VLFeat, an open source derivative of SIFT (Vedaldi & Fulkerson 2008). VLFeat is a C++ open source library implementation of computer vision algorithms such as HOG, SIFT, MSER, k-means and hierarchical k-means. This implementation of SIFT identifies features in each image by scaling, rotating, and identifying variations between the images such as changes in illumination conditions and camera viewpoint. Keypoints in the images are automatically identified and feature descriptors created.

Once the keypoint identification and descriptor assignment are complete, a sparse bundle adjustment system (Snavely, Garg, Seitz & Szeliski 2008, Snavely, Seitz & Szeliski 2008) is used to estimate camera pose and extract a sparse point cloud (an example is shown in figure 4).

Features that move across the area of interest, but are only present in a select number of images, will be automatically removed from the final 3D reconstruction. Although keypoints for these objects are created, as they are not present in a number of overlapping images and thus not suitable for the scene reconstruction they are automatically filtered from the final 3D scene (Lazebnik et al. 2007).

2) *Clustering View for Multi-view Stereo and Patch-based Multi-view Stereo:* To enhance the sparse data, the Clustering View for Multi-view Stereo (CMVS) (Lazebnik et al. 2007, Furukawa et al. 2010) and Patch-based Multi-view Stereo (PMVS2) algorithms (Lazebnik et al. 2007) are used sequentially to produce a dense point-cloud. CMVS decomposes the sparse point cloud



Fig. 4: The sparse point cloud generated for Bodowyr Burial Chamber.

into a manageable set of image clusters. PMVS then reconstructs the 3D structure of the object of interest in the images, producing a set of oriented points where both the position and the surface normal are estimated.

D. Output Work Flow

Once the final stages of the photogrammetry have been completed and the dense point-cloud created, a 3D mesh is generated. In order to produce a mesh, the areas between each of the dense points need to be triangulated. This can be achieved by running a point-to-mesh surface reconstruction, in this case we utilise Kazhdan et al.'s Poisson formulae for the calculation (Kazhdan et al. 2006). Kazhdan et al.'s algorithm considers all the points at once without utilising a bounding interval hierarchy, and is therefore resilient to noise in the data; this makes it ideal for a point-cloud dataset produced using photogrammetry (an example can be seen in figure 5).

The second stage of the output work flow is texture creation. After the high resolution mesh has been completed, an accompanying texture is also produced. This texture is created from an averaged mosaic from all the images used in the photogrammetry process.

Once a high resolution mesh has been generated, a low resolution version of the mesh must be created for display on the website. The high resolution mesh is decimated using Quadric Edge Collapse Decimation and saved in the X3D file format. The Quadric Edge Collapse Decimation produces an optimised mesh by determining



Fig. 5: The untextured mesh generated for Bodowyr Burial Chamber.

the most important edges of the mesh and reducing the polygons between them, and tries to keep the shape of the original model intact. The high resolution texture is mapped over the mesh, giving it a more aesthetically pleasing final output (figure 2 is an example of this).

E. Website Work Flow

The X3D file can be uploaded to the gallery and instantly viewed using the X3DOM plug-in (Behr et al. 2009). All of the uploaded models are freely available to download in X3D format, and in the future the high resolution models will also be available to download.

F. Research Portal Work Flow

A large portion of the platform yet to be implemented is the planned project 'research portal'. The research portal will allow the project to make all of the SfM and additional data generated throughout the life of the project freely available for all to download.

V. OPEN ARCHAEOLOGY

Archaeology has slowly been going through an information revolution, affecting the ways in which it is researched and published. These changes have come about as a result of an idea: being 'open'. Open source software, open access to archaeological data and open ethics. 'Open' has become an increasingly attractive thing to be; from research, to corporations and governments. Openness gives an air of transparency, ideas of public accountability and scientific repeatability, and as such provides a buzzword for perceived public good (Lake 2012).

The HeritageTogether project is no different, following established open-access concepts throughout every stage of the research process. All the research data produced

will be available for the digital community to use, re-analyse and re-interpret. This ‘openness’ will provide the general public, project contributor and the research community unprecedented access to an ongoing research project.

VI. CONCLUSION

HeritageTogether was established as an academic project, but is being developed with the intention of fostering a future digital community of enthusiastic contributors who can co-create the most extensive photographic archive of megalithic monuments in Wales, UK.

SfM – through SIFT, Bundler, CMVS and PMVS2 – has been used to create an online automated photogrammetry work flow for processing photographs uploaded by the general public and members of the HeritageTogether team. At present the automated photogrammetry system is activated by a member of the administration team, however, we plan on expending this responsibility to community members and contributors who have dedicated time to the project.

The web platform has been active for 6 months at the time of writing, in which time it has attracted a number of contributors who have uploaded over 9000 photographs to the website, allowing the creation of 50 models of different megalithic monuments.

VII. FUTURE WORK

The web platform has been purposely developed in existing software packages that are easy to use and maintain with the intention of training community members to manage the site after the completion of the academic work. The digital community of HeritageTogether can grow and continue to record data for future analysis and a more continuous observation of the condition of sites by members of the public.

Upon completion of the academic project, the collected photographs can be freely accessed by archaeological archives, such as the Archaeology Data Service (ADS) (*Archaeology Data Service: Homepage* n.d.), to update their photographic records. If the website continues to collect data, this could also be periodically used to update archives. The constructed 3D models and additional data will also be available through the research portal.

As the platform is undergoing continuous review and development based on the contributions and requirements of our growing digital community, numerous features are planned for improving the interface and functionality provided by the platform.

Over the course of the project we plan to improve the functionality of the web platform, building on our gallery system to create a virtual museum-style interface. This virtual museum system will display our gallery images, 3D models and archaeological information and interpretations.

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